Use of Electronic Tag Data and Associated Analytical Tools to Identify and Predict Habitat Utilization of Marine Predators

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Award Number: N00014-08-1-1195

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LONG-TERM GOALS

Key to assessing the risk of naval activities (such as sound exposure) on marine animals is an understanding of where animals occur and what factors motivate these movements. The rapid advancement of electronic tracking and remote sensing technologies has enabled researchers to link pelagic predator movements and oceanic processes. This information is critical for understanding distribution and residence time of vertebrates within an ocean area and for managing interactions with anthropogenic activities. This proposal will use the largest database of existing marine vertebrate tracking and behavior data to build upon the significant advances in tag technology, data analyses and management accomplished under the Tagging of Pacific Pelagics (TOPP) program. This will be accomplished by establishing a behavioral baseline to assess the potential costs of displacement in terms of reduced foraging success.

OBJECTIVES

1) Identify and map focal feeding, breeding, and migration routes.

2) Model spatio-temporal oceanographic habitat utilization and predict regions of animal occupancy and use based on oceanographic features.

3) Utilize this model framework to assess the impact of displacement from primary feeding areas due to disturbances (such as acoustic disturbance).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **Use Of Electronic Tag Data And Associated Analytical Tools To Identify And Predict Habitat Utilization Of Marine Predators**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California, Santa Cruz,100 Shaffer Rd.,Santa Cruz,CA,95060**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Key to assessing the risk of naval activities (such as sound exposure) on marine animals is an understanding of where animals occur and what factors motivate these movements. The rapid advancement of electronic tracking and remote sensing technologies has enabled researchers to link pelagic predator movements and oceanic processes. This information is critical for understanding distribution and residence time of vertebrates within an ocean area and for managing interactions with anthropogenic activities. This proposal will use the largest database of existing marine vertebrate tracking and behavior data to build upon the significant advances in tag technology, data analyses and management accomplished under the Tagging of Pacific Pelagics (TOPP) program. This will be accomplished by establishing a behavioral baseline to assess the potential costs of displacement in terms of reduced foraging success.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

APPROACH

There are two distinct components to this effort, each of which addresses a project objective. First, we will use existing TOPP tracking data to generate overall utilization distributions as well as single species distributions and further categorize track segments by behavioral state using a combination of state spaced models and the fractal landscape method to determine regions of area restricted search (ARS) (Jonsen et al. 2003; Jonsen et al. 2006; Tremblay et al. 2007). Next, we will model the links between oceanographic parameters and animal movement patterns. The output from these models will be used to develop predictive models of marine vertebrate distribution based on oceanographic parameters.

WORK COMPLETED

For the North Pacific Transition Zone, we completed monthly, seasonal, and yearly kernel density utilization distributions of elephant seals (Figures 6 and 7) using state-space modeled tracks from 2004-2008.

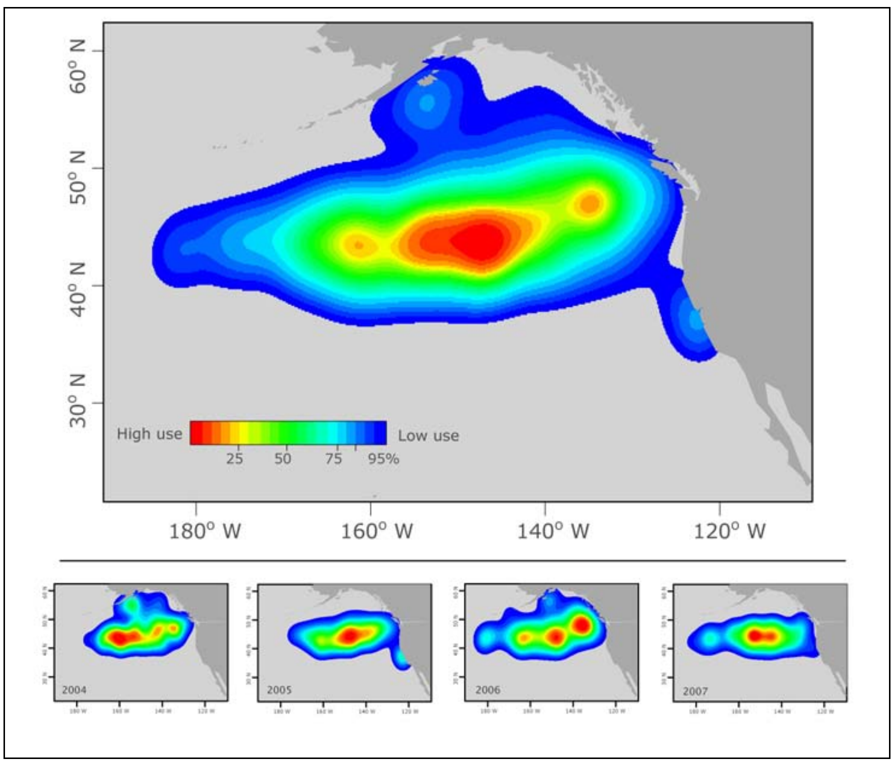

Figure 1: Utilization distributions of tagged female northern elephant seals during their post-molt migration, July-November 2004-2007

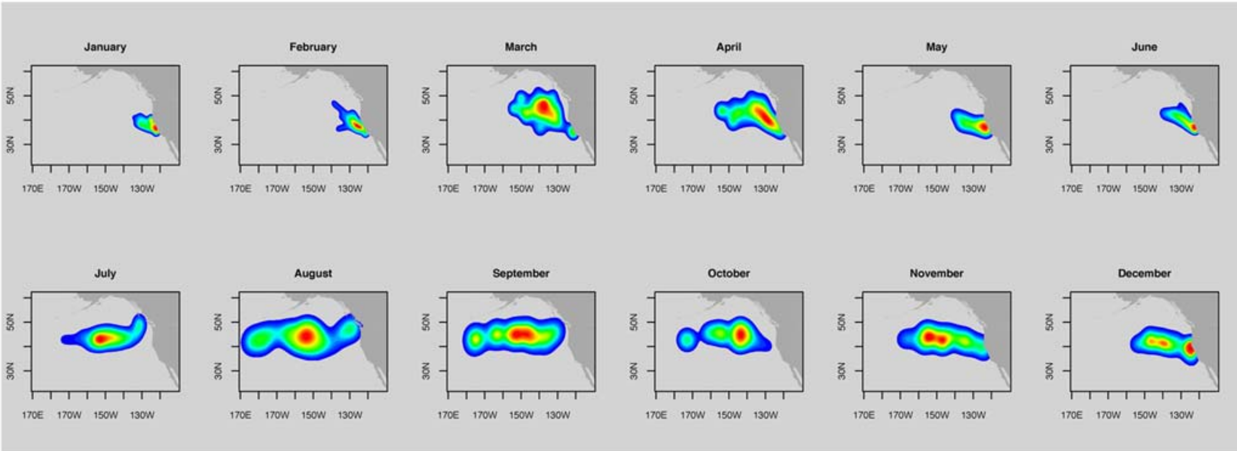

Figure 2: 2007 Monthly utilization distributions of tagged female northern elephant seals

Blue whale and California sea lion home range analyses were also completed using state-space modeled tracks; humpback whale tracks are currently being modeled. We conducted preliminary analyses to identify multi-species hotspots for marine mammals and other species in space and time (yearly, seasonally) for all three species in the California Current System.

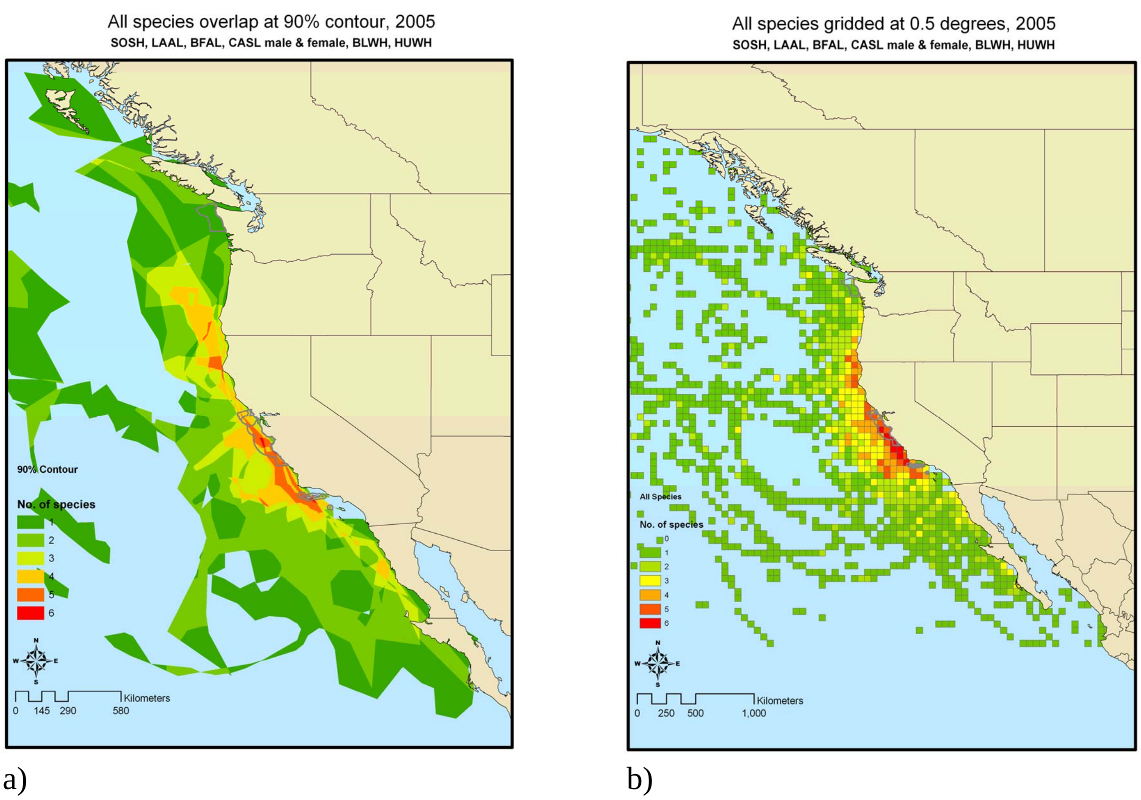

Figure 3: Multispecies hotspots in the California Current System using local convex hulls, and b) 0.5 degree grid cells

Habitat models

Foraging areas and home range analyses described above will be compared to modeled, predictive habitat maps constructed monthly and yearly for elephant seals. We are currently researching habitat variables thought to influence elephant seal presence or absence in a particular area and determining the best products available in terms of scale, quality, and availability. In addition to obtaining high resolution bathymetry and monthly sea surface temperature data, we recently obtained monthly science quality data for sea surface height deviation, chlorophyll-a, and primary production spanning from Jan-2004 to May-2008. Monthly salinity climatologies have also been obtained from the National Oceanographic Data Center (NODC). Working with monthly satellite derived data will help optimize the quality and quantity of data available for the study area while still being able to identify large mesoscale features such as persistent eddies. Other covariates that will be included in a habitat model have been generated in ArcGIS including Euclidian distance from continental shelf, and distance from land. The monthly position of the Transition Zone Chlorophyll Front (TZCF) was calculated by researchers at the southwest fisheries science center by applying smoothing algorithms along the 0.2 mg/m^3 isoclines of surface chlorophyll. Once these positions were determined, we used ArcGIS to create monthly Euclidian distance from TZCF grids. Current efforts are focused on sampling monthly environmental variables at intervals along all high-quality elephant seal tracks.

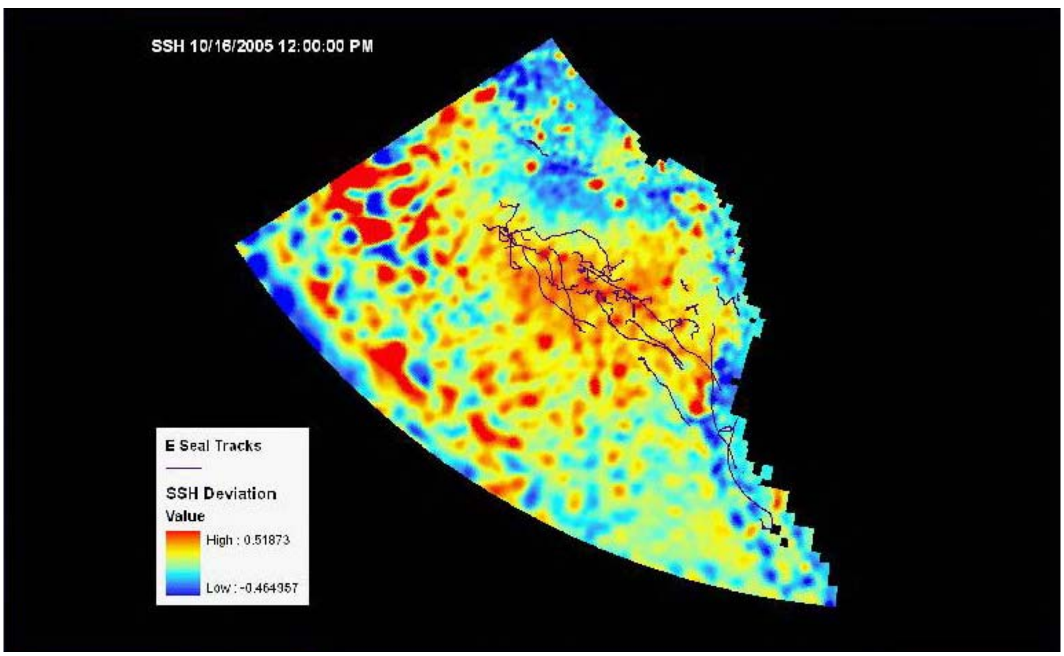

Figure 4: Sea surface height anomaly with elephant seal tracking data. ArcGIS will enable comprehensive comparison under a standard framework.

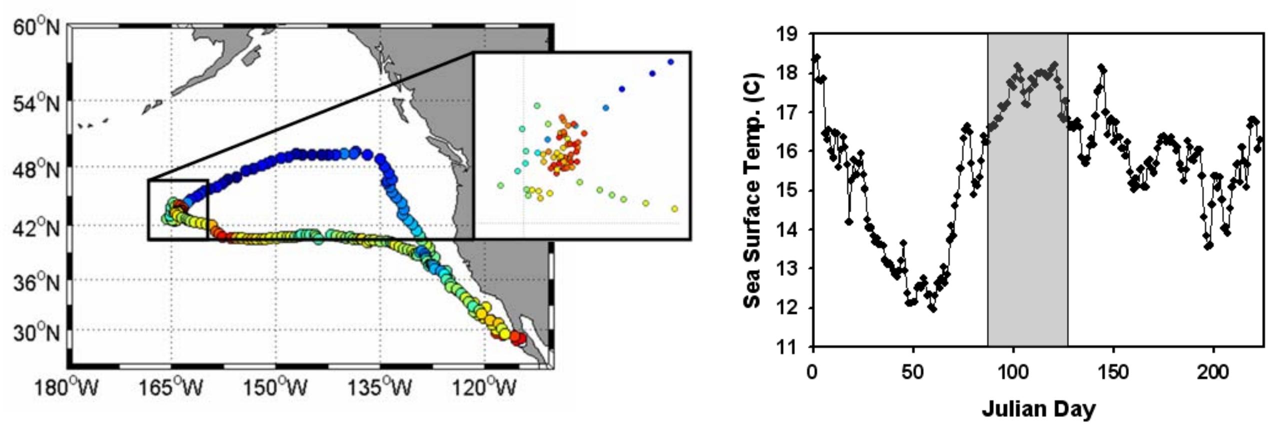

Figure 5: Sea surface temperature estimates collected from a time-depth recorder. These data will be used to investigate fine-scale habitat-use in conjunction with remotely sensed datasets.

RESULTS

We analyzed elephant seal diving and tracking data to assess the efficacy of a variety of tracking metrics that have been used to assess foraging behavior. Movement paths and diving activity data are frequently used to infer feeding locations of marine predators. Foraging metrics based on movement paths, e.g. from ARGOS satellite tracking, rely on the assumption that feeding takes place within regions of area-restricted search, while foraging metrics based on diving behavior assume bottom activity corresponds to prey capture. These metrics have rarely been compared to behavior-independent measures of foraging success. These foraging metrics were validated against a behavior-independent metric, change in drift rate, and against empirical measurement of energy gain over the trip to sea. Elephant seals routinely exhibit dives in which the animals passively drift through the water column. The vertical rate of drift, which can be easily measured from time-depth recorder data, is related to the animal's relative body composition (i.e. adipose-lean tissue ratio). During a foraging migration, the animal will feed and increase the relative proportion of adipose tissue, thus increasing its own buoyancy. We showed that drift dive analysis can be used to estimate foraging success in the northern elephant seal by demonstrating a strong relationship between the change in drift rate over a foraging migration and empirical measurement of total energy gain estimated from body composition measures. Changes in buoyancy that are reflective of foraging success can be resolved to a time scale of several days. This method is advantageous because drift rate can be recorded simultaneously with tracking data from complete elephant seal foraging migrations to identify spatial patterns of feeding success.

Given this elephant seal specific index of foraging behavior and success, we compared a range of foraging metrics that are applicable to a variety of species to see which are the most reliable indicators of feeding success. Among the 10 foraging metrics tested, the simple measure of transit rate consistently provided the best estimate of foraging success, a result that is encouragingly applicable to a broad range of species.

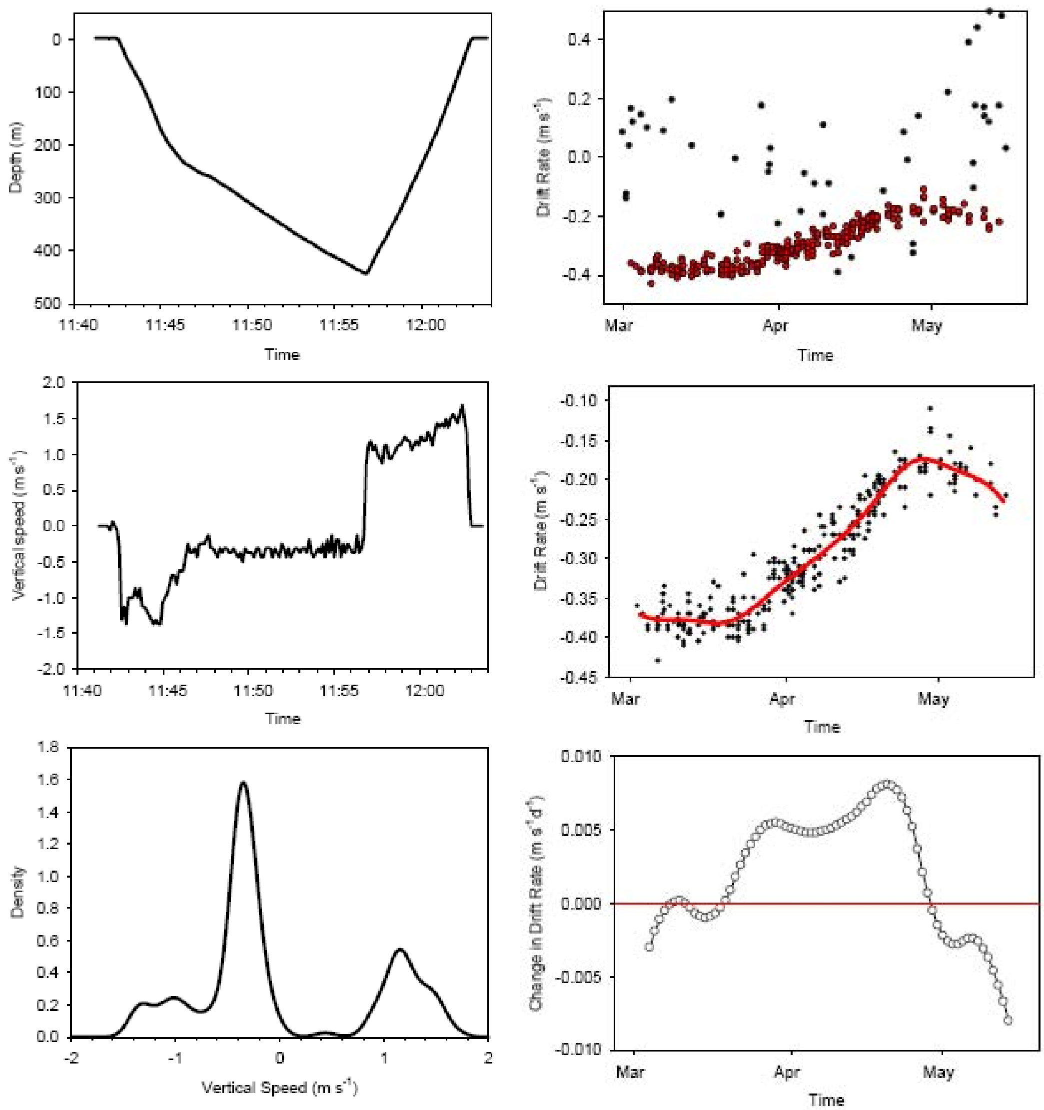

Figure 6. A summary of the analytical steps to calculate daily changes in drift rate from time-depth recorder data. Left hand panels represent key measures in this process for an individual drift dive. Right hand panels represent those for an entire foraging migration.

Additionally, the drift rate data have been compiled across years to identify habitat of critical importance to elephant seals. This analysis revealed the significance of many areas outside of focal foraging areas, formerly thought to simply be transit periods.

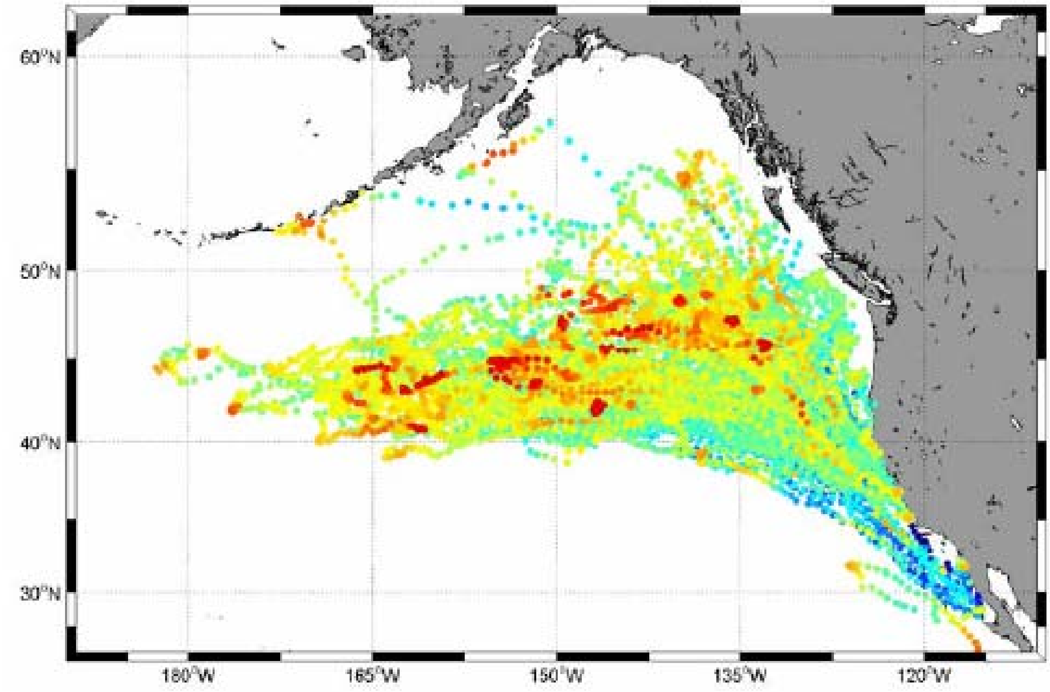

Figure 7: Locations of foraging success from 4 years of elephant seal tagging, as estimated from changes in buoyancy.(warmer colors indicate positive changes in buoyancy, i.e. mainly lipid deposition, while cooler colors indicate negative changes in buoyancy).

State-space location and behavior estimates have been produced for all northern elephant seal tracks collected prior to mid-2008. Results to date have been collated into a single file, extensively commented, and made available to other project participants (mostly graduate students working with Dan Costa). A similar analysis, comments, and file were produced for the entire California sea lion tracking dataset in July 2009.

ARGOS location estimates do not include complete error estimations, and for many marine organisms, the most commonly acquired locations (Location Class 0, A, B, or Z) are provided with no declared error estimate. We compared the accuracy of ARGOS locations to those obtained using Fastloc GPS from the same electronic tags (Figure 8) on five species of pinnipeds: 9 California sea lions (*Zalophus californianus*), 4 Galapagos sea lions (*Zalophus wollebaeki*), 6 Cape fur seals (*Arctocephalus pusillus pusillus*), 3 Australian fur seals (*A. p. doriferus*) and 5 northern elephant seals (*Mirounga angustirostris*).

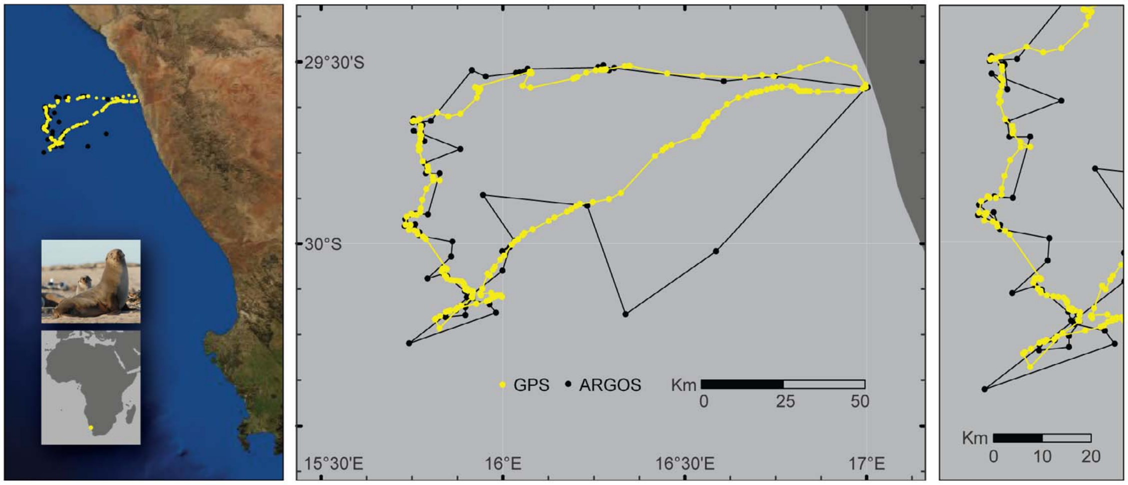

Figure 8: A representative track from a female Cape fur seal foraging off the western coast of South Africa obtained by ARGOS (black) and Fastloc GPS (yellow) locations. All filtered locations are presented in this figure, while the comparison between ARGOS and GPS used only locations that were obtained within 5 min of each other.(Costa et al. In Review).

The ARGOS errors measured here are greater than those provided by ARGOS, but within the range of other studies. Locations of species that make short duration dives and spend extended periods on the surface (sea lions and fur seals) had less error than species like elephant seals that spend more time underwater and make longer duration dives.

IMPACT/APPLICATIONS

Critical to determining the impact of exposure to naval operations on marine animals is relating the intensity and duration of an exposure to the time animals spend in proximity to the source, and the biological function of that time. The proposed predictive models of critical marine animal habitat utilization are the essential behavioral components to determine whether and where naval operations might impact marine mammals and other marine vertebrates.

RELATED PROJECTS

JIP: Relating Behavior and Life Functions to Populations Level Effects in Marine Mammals: An empirical and modeling effort to develop the PCAD model. Contract JIP 22 07-23

PUBLICATIONS

Simmons, S.E., Crocker, D.E., Hassrick, J.L., Kuhn, C.E., Robinson, P.E. Tremblay, Y. and Costa, D.P. in review. Climate scale hydrographic features related to foraging success in a capital breeder: the northern elephant seal (*Mirounga angustirostris*). Endangered Species Research.

Costa, D.P., Robinson, P.W., Arnould, J.P.Y. Harrison, A. Simmons, S.E., Hassrick, J.L., Hoskins, A. Kirkman, S. Oosthuizen, H. Villegas, S. in review. Accuracy of ARGOS locations of animals at sea estimated using Fastloc GPS. PloS one.

Hassrick, J. L., Crocker, D. E., Teutschel, N. M., McDonald, B. I., Robinson, P. W., Simmons, S. E., and Costa, D. P. in review. Age and mass impact oxygen stores and dive duration in adult female northern elephant seals. *Journal of Experimental Biology*.

Tremblay. Y., Robinson, P.W., Kappes. M., Kuhn, C.E., Shaffer, S.A., Mc Donald, B., Simmons, S. E., Crocker, D.E., and Costa, D.P. in review. Spatiotemporal scales of foraging in marine top-predators. Endangered Species Research.

Bailey, H., Mate, B.R., Palacios, D.M., Irvine, L., Bograd, S.J. and Costa, D.P. in press. Behavioural estimation of blue whale movements in the Northeast Pacific from state-space model analysis of satellite tracks. Endangered Species Research.

Yoko, M. Andrews, R., Sato, K., Kato, A., Naito, Y. Costa, D. in press. 3D resting behavior of northern elephant seals: drifting like a falling leaf. Biology Letters.

Simmons, S.E. Tremblay, Y. and Costa, D.P. 2009. Pinnipeds as ocean temperature samplers: calibrations, validations and data quality. Limnology and Oceanography Methods 7: in press

Villegas-Amtmann, S. and Costa, D.P. in press. Physiological plasticity in response to foraging behaviour and pregnancy in a diving predator, the galapagos sea lion. Functional Ecology.

Villegas-Amtmann, S., Atkinson, S and Costa, D.P. in press. Asynchronous breeding cycle in Galapagos sea lions revealed by seasonal progesterone concentrations. Journal of Mammalogy.

Tremblay, Y. Bertrand, S., William, R. H., Kappes, M.A., Costa, D.P. and Shaffer, S.A. 2009. A Review of Analytical Approaches to Investigate Seabird-Environment Interactions. Marine Ecology Progress Series. 391: 153–163.

Costa, D.P., Tremblay, Y. and Hayes, S. 2009. Research on Higher Trophic Levels. Oceanography in 2025: Proceedings of a Workshop http://www.nap.edu/catalog/12627.html Deborah Glickson, Editor; Committee on Oceanography in 2025: A Workshop; National Research Council ISBN: 0-309-13746-2, 198 pages

Shaffer, S.A., Weimerskirch, H., Scott, D., Pinaud, D., Thompson, D.R., Sagar, P.M., Moller, H., Taylor, G.A., Foley, D.G., Tremblay, Y., and Costa, D.P. 2009. Spatio-temporal habitat use by breeding sooty shearwaters (*Puffinus griseus*). *Marine Ecology Progress Series*). *Marine Ecology Progress Series*. Vol. 391: 209–220.

Hoskins, A.J., Dann, P. Ropert-Coudert, Y. Kato, A., Chiaradia, A. Costa,D.P. Arnould, J.P.Y. 2008. Foraging behaviour and habitat selection of the little penguin (*Eudyptula minor*) during early chick rearing. Marine Ecology Progress Series 366:293-303.

Harris, R., Buckley, L., Campbell, R., Chiba, S., Costa, D., Dickey, T., Gifford, D., Irigoien, X., McKinnell, S., Kiorboe, T., Möllmann, C., Ohman, M., Peterson, B., Runge, J., Saiz,, E. St John, M., Wiebe, P. 2009. Dynamics of marine ecosystems: observation and experimentation. Ch 6. GLOBEC Book.